

CLAIMS

1. A detection apparatus to detect magnetic fields comprising:
 - an first alteration element having a response curve to an applied electromagnetic field, the response curve exhibiting hysteresis between a plurality of stable states such that transition regions exist between the stable states;
 - a source of electromagnetic radiation, the electromagnetic radiation impinging on the first alteration element;
 - a source of an alternating electromagnetic field applied to the first alteration element, the alternating electromagnetic field of sufficient strength to switch the first alteration element between the stable states, a characteristic of the electromagnetic radiation being altered dependent on the alternating electromagnetic field and an electromagnetic field of a subject; and
 - a detector configured to detect the characteristic of the electromagnetic radiation impinging on the detector, the electromagnetic radiation impinging on the detector having been altered when the first alteration element was in one of the transition regions.
2. The detection apparatus of claim 1, wherein the electromagnetic radiation is light and the characteristic is polarization of the light.
3. The detection apparatus of claim 1, further comprising an amplification material disposed close enough to the first alteration element to amplify an internal electromagnetic field of the first alteration element.
4. The detection apparatus of claim 1, wherein the alternating electromagnetic field applied to the first alteration element comprises an alternating electromagnetic field of high frequency during detection and a low frequency field to remagnetize the first alteration element.

5. The detection apparatus of claim 1, wherein the detection apparatus is configured to measure a magnetic field of a heart.

6. The detection apparatus of claim 1, wherein the detection apparatus is configured to track particles introduced intentionally to a human.

7. The detection apparatus of claim 1, further comprising a second alteration element having a response curve substantially identical to the first alteration element, the second alteration element disposed so as to be affected by the alternating electromagnetic field substantially identically as the first alteration element while remaining substantially unaffected by the electromagnetic field of the subject, the detector configured to detect the characteristic of the electromagnetic radiation from both the first and second alternation elements impinging on the detector that have been altered when the first and second alteration elements were in one of the transition regions and provide an output based on a difference between the characteristic of the electromagnetic radiation from the first and second alternation elements.

8. The detection apparatus of claim 1, wherein the detector is configured to detect the characteristic of the electromagnetic radiation impinging on the detector that has been altered only when the first alteration element was in one of the transition regions.

9. The detection apparatus of claim 1, further comprising an optimization apparatus to optimize the hysteresis characteristic such that an operating point is substantially maintained by adjusting at least one of an amplitude and a frequency of the alternating electromagnetic field to substantially maintain the operating point.

10. The detection apparatus of claim 9, wherein the optimization apparatus monitors the hysteresis characteristic and adjusts the alternating electromagnetic field only if the hysteresis characteristic has changed by a predetermined amount.

11. A detection apparatus to detect magnetic fields comprising:
a first magneto-optical element that exhibits a response, in the form of Faraday rotation, to an applied magnetic field, a hysteresis characteristic of the Faraday rotation exhibiting transition regions between a plurality of stable states;
a light source to emit light that impinges on the first magneto-optical element;
a modulation element to apply a time-varying magnetic field of sufficient strength to switch the first magneto-optical element between the stable states; and
a detector configured to detect a change in the light caused by a reaction of the first magneto-optical element to a magnetic field of a subject that occurred when the first magneto-optical element was in one of the transition regions.

12. The detection apparatus of claim 11, wherein the modulation element is configured to apply a time-varying magnetic field of frequency substantially higher than 60 Hz.

13. The detection apparatus of claim 11, further comprising a magnetic material having a high permeability and disposed sufficiently close to the first magneto-optical element to amplify an internal magnetic field in the first magneto-optical element formed by an external magnetic field impinging on and penetrating the first magneto-optical element.

14. The detection apparatus of claim 11, wherein the detector is configured in a gradiometer arrangement to subtract a background signal from a subject signal

supplied from the first magneto-optical element affected by the magnetic field of the subject.

15. The detection apparatus of claim 7, further comprising a second magneto-optical element upon which the light impinges and that is affected substantially the same as the first magneto-optical element by the time-varying magnetic field, the second magneto-optical element configured to be substantially unaffected by the magnetic field of the subject and supplying the background signal.

16. The detection apparatus of claim 11, further comprising a trigger configured to detect an initialization signal from the magnetic field of the subject and transmit a trigger pulse to the detector.

17. The detection apparatus of claim 11, further comprising shielding to shield components of the detection apparatus from sources of electromagnetic radiation causing noise in the components.

18. The detection apparatus of claim 17, wherein the shielding is configured to additionally shield a source of the magnetic field of the subject.

19. The detection apparatus of claim 17, wherein a source of the magnetic field of the subject remains uncovered by the shielding.

20. The detection apparatus of claim 11, further comprising a vibration-isolating platform on which components of the detection apparatus are disposed.

21. The detection apparatus of claim 20, wherein the vibration-isolating platform is large enough to additionally hold a source of the magnetic field of the subject.

22. The detection apparatus of claim 11, wherein the first magneto-optical element comprises a doped YIG thin film has a thickness of less than about three microns.

23. The detection apparatus of claim 22, wherein the YIG film is doped with at least Bi.

24. The detection apparatus of claim 22, wherein the YIG film is formed from amorphous or single crystal material.

25. The detection apparatus of claim 11, further comprising a single nonmagnetic frame upon which optical components of the detection apparatus are mounted.

26. The detection apparatus of claim 11, wherein the modulation element is configured to apply a time-varying magnetic field of high frequency during detection and a low frequency field to remagnetize the first magneto-optical element.

27. The detection apparatus of claim 11, wherein the excitation source is a laser.

28. The detection apparatus of claim 11, further comprising an expander to enlarge an area of light from the light source impinging on the first magneto-optical element.

29. The detection apparatus of claim 11, wherein the detection apparatus is configured to measure a magnetic field of an organ or bodily system of an animal.

30. The detection apparatus of claim 11, wherein the detection apparatus is configured to measure a magnetic field of an organ or bodily system of human.

31. The detection apparatus of claim 30, wherein the organ is a heart.

32. The detection apparatus of claim 31, further comprising a trigger configured to detect a cardiac pulse waveform and transmit a trigger pulse to the detector.

33. The detection apparatus of claim 11, wherein the detection apparatus is configured to track magnetic particles introduced intentionally to an animal.

34. The detection apparatus of claim 11, wherein the detector is characterized in that the change in the light detected is caused only when the first magneto-optical element was in one of the transition regions.

35. The detection apparatus of claim 11, further comprising an optimization apparatus to optimize the hysteresis characteristic such that an operating point is substantially maintained.

36. The detection apparatus of claim 35, wherein the operating point provides maximum magnetic field sensitivity.

37. The detection apparatus of claim 35, wherein the optimization apparatus adjusts at least one of an amplitude and a frequency of the time-varying magnetic field to substantially maintain the operating point.

38. The detection apparatus of claim 37, wherein the optimization apparatus comprises a detection element that detects the response of the first magneto-optical element and transmits an optimization signal to optimization electronics that measure a slope of the transition region near the operating point and provide feedback to the modulation element to adjust the time-varying magnetic field.

39. The detection apparatus of claim 38, wherein the optimization apparatus monitors the hysteresis characteristic of the first magneto-optical element

and adjusts the time-varying magnetic field only if the hysteresis characteristic has changed by a predetermined amount.

40. A method of detecting magnetic fields comprising:
providing a first magneto-optical element that exhibiting a response, in the form of Faraday rotation, to an applied magnetic field, a hysteresis characteristic of the Faraday rotation exhibiting transition regions between a plurality of stable states;
emitting light from a light source that impinges on the first magneto-optical element;
applying a time-varying magnetic field of sufficient strength to switch the first magneto-optical element between the stable states; and
detecting a change in the light caused by a reaction of the first magneto-optical element to a magnetic field of a subject that occurred when the first magneto-optical element was in one of the transition regions.

41. - The detection method of claim 40, further comprising applying a time-varying magnetic field of frequency substantially higher than 60 Hz during detection.

42. The detection method of claim 40, further comprising amplifying an internal magnetic field of the first magneto-optical element using a magnetic material disposed adjacent to the first magneto-optical element and having a high permeability.

43. The detection method of claim 40, further comprising configuring components used in the detection method in a gradiometer arrangement to subtract a background signal from a subject signal supplied from the first magneto-optical element affected by the magnetic field of the subject.

44. The detection method of claim 44, further comprising providing a second magneto-optical element upon which the light impinges and that is affected

substantially the same as the first magneto-optical element by the time-varying magnetic field, the second first magneto-optical element configured to be substantially unaffected by the magnetic field of the subject and supplying the background signal.

45. The detection method of claim 40, further comprising shielding components used in the detection method from sources of electromagnetic radiation causing noise in the components.

46. The detection method of claim 45, further comprising shielding a source of the magnetic field of the subject.

47. The detection method of claim 45, further comprising leaving a source of the magnetic field of the subject unshielded.

48. The detection method of claim 40, further comprising isolating components used in the detection method from vibrations.

49. The detection method of claim 48, further comprising isolating a source of the magnetic field of the subject from the vibrations.

50. The detection method of claim 40, wherein the first magneto-optical element comprises a doped YIG thin film that has a thickness of less than about three microns.

51. The detection method of claim 50, wherein the YIG film is doped with at least Bi.

52. The detection method of claim 50, wherein the YIG film is formed from amorphous or single crystal material.

53. The detection method of claim 40, further comprising applying a time-varying magnetic field of high frequency during detection and a low frequency field to remagnetize the first magneto-optical element.

54. The detection method of claim 40, further comprising expanding an area of the light emitted from the light source.

55. The detection method of claim 40, further comprising measuring a magnetic field of an organ or bodily system of an animal.

56. The detection method of claim 40, further comprising measuring a magnetic field of an organ or bodily system of a human.

57. The detection method of claim 40, further comprising measuring the magnetic field of a heart.

58. The detection method of claim 57, further comprising detecting a cardiac pulse waveform and transmitting a trigger pulse to initiate detection.

59. The detection method of claim 40, further comprising tracking magnetic particles introduced intentionally to an animal.

60. The detection method of claim 40, wherein detecting only the change in the light that occurred when the first magneto-optical element was in one of the transition regions.

61. The detection method of claim 40, further comprising optimizing the hysteresis characteristic such that an operating point is substantially maintained.

62. The detection method of claim 40, further comprising optimizing the hysteresis characteristic such that a maximum magnetic field sensitivity is substantially maintained.

63. The detection method of claim 61, further comprising adjusting at least one of an amplitude and a frequency of the time-varying magnetic field to substantially maintain the operating point.

64. The detection method of claim 63, further comprising detecting a magnetization of the first magneto-optical element, measuring a slope of the transition region near the operating point and providing feedback to adjust the time-varying magnetic field.

65. The detection method of claim 64, further comprising monitoring the hysteresis characteristic and adjusting the time-varying magnetic field only if the hysteresis characteristic has changed by a predetermined amount.